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LCA IN JAPAN

LCA in Japan in the twenty-first century

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1 Introduction

Year 2011 was the most unforgettable year for the Japanese people in the twenty-first century. The huge earthquake occurred in the north east region of Japan on March 11th, which resulted in a Tsunami and a nuclear disaster in Fukushima. We received a lot of anxious inquires about our safety from all over the world. Once again, we would like to express our thanks for all the sympathy and kind messages. Although there are still so many things to do, recovery is gradually but certainly in progress. On the other hand, we currently have tough debates on consensus building for restarting or eliminating nuclear power plants in Japan. The situations have been rather chaotic, but decision making is being required to avoid the crisis of electricity supply. So, everybody in Japan cannot help in considering what sustainability is.

Concerning Life Cycle Assessment (LCA), 12 years have passed since the first special issue for LCA in Japan was published in 2000 (vol. 5, no. 5). At that time, LCA in Japan was in the period of development in accordance with ISO standardization. The LCA database authorized by industrial associations and the Life Cycle Impact assessment Method based on Endpoint modeling (LIME) were being developed in the first-term LCA Project supported by the Ministry of Economy, Trade and Industry (METI). Since then, there have been great progresses in scientific achievements and implementations by LCA researchers and practitioners. LCA has been widespread in Japanese industries, the results of which were used for designing their products and communication with customers, etc. For example, TOYOTA has introduced the 'ECO-VAS system' for implementing LCA in designing all of their automobiles since 2005 (TOYOTA 2005). In addition, the attention of Carbon Footprint has further enhanced dispersing LCA the last couple of years. So, it is not an easy task to cover all the LCA activities in Japan.

In this paper, we focus on the progresses in LCA in Japan since 2000 from the viewpoint of scientific achievements, especially the establishment of Institute of LCA, Japan, Development of Life Cycle Impact Assessment Methodology, Input–Output and hybrid LCA, and LCA database.

2 Establishment of institute of LCA, Japan

One of the milestones of LCA in Japan was the establishment of the Institute of LCA, Japan (ILCAJ) in 2005. The goal of ILCAJ is to promote academic activities related to

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life-cycle thinking and to share expert knowledge with colleagues from wide ranging backgrounds. The number of the members of ILCAJ has continuously increased since 2005. In June 2012, the numbers of members, student members, and supporting members were 410, 195, and 46, respectively. The chairman of ILCAJ was Prof. Ryoichi Yamamoto, followed by Prof. Atsushi Inaba.

The main activities of ILCAJ are (1) publishing *Journal of LCA, Japan* (*J LCA Jpn*), (2) holding the domestic conference, (3) holding the International Conference on Ecobalance, (4) prize giving, (5) organizing research groups, etc. The details are the following.

J LCA Jpn has been successfully published as a quarterly since the first issue in 2006, which contained peer-reviewed research papers, commentaries and discussions, (technical) reports, lecture notes, and presentations of research groups in Japan, etc. Almost all issues have been special issues focusing on a designated topic of which the contents and number of papers with peer review are shown in Table 1.

There have been not so many but a certain number of papers with peer-review related to case studies as well as methodological developments. JLCA Jpn has aimed to be a bridge between the LCA community of Japan and that of the whole world. Some selected research papers from *Int J Life Cycle Assess* have been translated into Japanese and published in *J LCA Jpn*. Papers published in *J LCA Jpn* can also be submitted to *Int J Life Cycle Assess* for publication following peer review. We hope that this collaboration will stimulate the global exchange of information through professional pathways.

The domestic conference has been held annually since 2006 counting over 400 participants over the years. The last annual conference, held at Tokyo University of Science in March 2012, attracted 410 participants, 150 of which were the students who were involved in LCA researches for their thesis at universities. There were 166 oral and 94 poster presentations and the proceedings have been disclosed to the public via Internet, https://www.jstage.jst.go.jp/browse/ilcaj/-char/ja. Some of the presenters at the domestic conference submitted their papers to *Journal of LCA, Japan* and were published with peer-review (see Table 1). So, the annual domestic conference has quite successfully contributed to activating the members in exchanging information and ideas as well as education for LCA and its related fields.

The International Conference on Ecobalance was also held every 2 years, attracting approximately 400 participants every time. The conference report has been published in this journal (Nansai et al. 2011), so we will not go into detail in this editorial. The next conference will be held in Yokohama coming November. We expect a lot of LCA experts and practitioners to gather at this conference.

3 Development of life cycle impact assessment methodology—LIME

When the LCA Project began in 1998, the main traditional integration method was a one based on midpoint modeling whereby impact categories were weighted directly from the result of characterization to gain a single index. However, a problem was pointed out concerning the method based on midpoint modeling: transparency and reliability were considerably insufficient because the method compared ten or more impact categories simultaneously almost without showing information on how much environmental impact actually arose.

Moreover, the usefulness of the assessment method based on endpoint modeling, which minimizes the number of items for weighting and carries out integration by comparison of the items through assessment of damage to human health and biodiversity at the endpoint level, has been recognized internationally. After the proposals of European researchers such as Müller-Wenk (1997), Hofstetter (1998), and Goedkoop and Spriensma (1999) were made, the methodology of using the result of damage assessment for integration rapidly attracted attention. Although many of the latest methods for LCIA (Eco-indicator 99, EPS, ExternE) are based on endpoint modeling, Japan was required to develop its own LCIA method based on endpoint modeling, because even if inventory is the same, the amount of damage differs depending on environmental conditions (such as weather and population density).

LIME1, which was developed in the first-term LCA Project, was published in 2005 as a method that was developed in Japan and reflected the environmental conditions in Japan and the most advanced methods in the field of environmental science (Itsubo and Inaba 2005). This is the first method in the world including all of the main steps of LCIA (characterization, damage assessment, and weighting) in one specific method. Potential environmental impacts of 11 types of impact categories and 4 types of damage categories (human health, social assets, biodiversity, and primary productivity) can be evaluated from this method. Several damage assessment models were developed (Hayashi et al. (2006), Hayashi et al. (2004)). Advanced method in the field of environmental economics enabled to estimate external cost as a result of weighting (Itsubo et al. 2004a, b).

LIME was developed as an LCIA method that reflects environmental and social conditions in Japan. Since the publication of this method, many domestic companies have used this method for the environmental assessment of their products and businesses. Through the use of LIME spreading in this way, problems to be corrected from various viewpoints have been clarified.

LIME2 was developed to solve the issues (Itsubo and Inaba 2012). Research and development was carried out in

Table 1 Contents in *Journal of LCA, Japan*

Year	Vol., no.	Title of special issue	Number of papers with peer review	
			Methodological development	Case study and others
2005	1, 1	Expectations on LCA	0	0
	1, 2	LCA database and software	0	1 (0)
	1, 2	Eco-efficiency	0	0
2006	2, 1	Application of input–output tables to LCA	3 (3)	3 (3)
	2, 2	Current status of LCA activities	1 (1)	2 (2)
	2, 3	Contributions from 1st annual meeting	4 (3)	6 (3)
	2, 4	LCA on recycling-oriented society	1 (1)	5 (2)
2007	3, 1	Life cycle impact assessment	1 (1)	1 (1)
	3, 2	-	1	1
	3, 3	Sustainable consumption	1 (1)	2 (1)
	3, 4	Contributions from the 2nd annual meeting	0	3 (2)
2008	4, 1	Architectural efforts on life cycle assessment in Japan	1 (0)	3 (1)
	4, 2	LCA in foods	0	1 (0)
	4, 3	Eco-design	2 (1)	4 (0)
	4, 4	Contributions from the 3rd annual meeting	3 (3)	4 (3)
2009	5, 1	LCA for social systems: toward the establishment of social/dynamic LCA	4 (2)	7 (3)
	5, 2	Green purchasing and environmental label	2 (1)	2 (2)
	5, 3	Life cycle thinking and environmental education	2 (2)	2 (1)
	5, 4	Contributions from the 4th annual meeting	4 (3)	7 (3)
2010	6, 1	Sociogeochemistry	0	1 (1)
	6, 2	MFA/LCA for management of material stocks	0	1 (1)
	6, 3	Footprint	1 (0)	4 (2)
	6, 4	Contributions from the 5th annual meeting	0	5 (4)
2011	7, 1	Life cycle assessment of food and green industry	3 (0)	3 (0)
	7, 2	Photovoltaic power generation and smart grid	0	3 (1)
	7, 3	Life cycle impact assessment (2)	1 (1)	1 (0)
	7, 4	Introduction of LCA to infrastructure development the Great East Japan earthquake	1 (1)	1 (1)
2012	8, 1	Contributions from the 6th Annual Meeting	0	8 (7)
	8, 2	Element strategy	0	3 (0)

Note: Figures in parentheses are those related to the special issue

the second-term LCA national project of Japan (METI and NEDO 2003 to March 2007). Main characteristics of the updated version of LIME are as follows:

1. Analysis of the uncertainty and sensibility of damage factors and integration factors: A list of damage factors and integration factors including statistical values such as standard deviation and variation coefficients were released to the public.
2. Development of weighting factors that reflect the Japanese people's views on the environment: discussions were carried out to develop weighting factors, increasing social consensus based on nationwide random sampling (Itsubo and Inaba 2012).
3. Development of environmental impact assessment methods for indoor air contamination and noise: 17 types of impact categories have been covered to improve the comprehensiveness of LCIA.

At present, the trend of LCIA research has shifted from the developing stage to the execution phase. Advanced Japanese companies use the LCIA method to various types of applications such as environmental accounting, eco-efficiency (Itsubo et al. 2004a, b), material flow cost accounting (Kokubu et al. 2006), cost benefit analysis (Motoshita et al. 2004; Ebisu et al. 2008) and integrated assessment model (Tokimatsu et al. 2006) as well as product LCA. Since the publication of this method, LCA Society of Japan launched the LIME2 working group to achieve the accumulation of case example study for the effective dissemination thereof to society. LCA Society of Japan (2009) published a variety of case study results carried out by 20 Japanese companies.

4 Development of input–output and hybrid LCA

With the evolution of LCA in Japan, the application of input–output tables (IOTs) to LCA has been extensively attempted from an earlier time. In particular, strong attention has been paid to the hybrid approach of process-LCA and input–output (IO)-LCA (Moriguchi et al. 1993; Hondo et al. 1996). Subsequently, a dozen peer-reviewed articles that contribute to the development of IO and hybrid LCA have been published. This section introduces the representative works by Japanese colleagues over the last 12 years (2001–2012).

4.1 Application of input–output tables to life cycle inventory

In Japan, many LCA studies have used the traditional Input–Output Analysis (IOA) and hybrid method to compile life cycle inventories of products, technologies, and services (e.g., Hondo 2005; Kagawa et al. 2011). Such extensive use is not only because the power of IOA is understood, but also because Japan has a very detailed, sophisticated IOTs and environmental database corresponding to IOTs (Nansai et al. 2003). On the other hand, life cycle inventories using IOA have various errors and uncertainties due its own problems (Suh et al. 2004). Therefore, besides the development of a hybrid analysis method (Hondo 2005), Hondo et al. (2002) discusses controlling their errors and uncertainties with sensitivity and uncertainty analyses.

An important source of uncertainties in IOA is 'import assumption'. IOA generally assumes that the imported commodities are produced using the same technology and structure of domestic industries. Thus, results of IOA of countries that rely heavily on imports are subject to a relatively high uncertainty (Suh et al. 2004). In order to reduce the uncertainty, Hondo et al. (1996) proposed an IO-based hybrid method, which is still employed to a representative LCA database in Japan (AIJ 2006). More recently, in order to overcome the uncertainty caused by 'import assumption', Nansai et al. (2009a) developed a global link input–output (GLIO) model comprising 804 economic sectors in Japan and 230 foreign countries and regions. The GLIO model was applied to calculate consumption-based GHG emission in Japan (Nansai et al. 2012b).

Instead of life cycle inventory analysis, IOTs are also applied to setting system boundary. Hondo and Sakai (2001) propose a consistent and practical method for system boundary definition, which allows for quantitatively and objectively identifying important processes and flows.

4.2 Waste input–output model

Nakamura and Kondo (2002) proposed a new scheme of hybrid LCA termed the waste input–output (WIO) model, which explicitly takes into account the interdependence between the flow of goods and waste. The WIO model has been used for various analyses and assessments such as evaluation of alternative life-cycle strategies for end-of-life electric home appliances (Kondo and Nakamura 2004), eco-efficiency analysis using the WIO linear programming model (Kondo and Nakamura 2005), and life cycle costing of air conditioners with different energy efficiency (Nakamura and Kondo 2006). The use of the WIO model in the field of sustainable consumption studies is also interesting. Takase et al. (2005) extend the WIO model to analyze households' consumption patterns considering income rebound effects, and Kagawa (2005) developed a modified WIO model that can endogenously treat the dependent relationship between household consumption and household waste generation.

Based on a series of previous studies, Kondo and Nakamura (2009) provide concepts and applications of the WIO model from a broad perspective. More recently, by expanding the WIO model, Nakamura et al. (2010) propose a new methodology for identifying the physical input–output flow of individual materials.

4.3 Environmental assessments and analyses based on life cycle thinking

IOTs are not just a tool to assist life cycle inventory analysis, they have also been used for environmental assessments and analyses based on life cycle thinking (e.g., Hondo et al. 2006; Nansai et al. 2009b). Hondo et al. (2006) developed an inter-temporal linear programming model using Japanese IOT to explore the optimal mix of technologies for CO_2 minimization in an entire society. Nansai et al. (2009b) performed a decomposition analysis of CO_2 emissions induced by households to highlight the increasing importance of indirect energy and materials consumption by services in the context of climate change policy. Kagawa (2012) overviewed the frontiers of environmental IOA including various works in not only our country but also around the world. IOTs have a wide range of potential use in future research based on life cycle thinking.

5 Development of LCA database

The features of major Japanese LCI databases are summarized in Table 2. The LCA Society of Japan (JLCA) database (JLCA 2012) was developed in the LCA national project and opened to the public in 2003. After the national project was finished in 2006, industry associations have voluntarily continued to collect their products data to add/revise their inventory datasets. To add a dataset to the database, it has to be reviewed by the LCA database committee of JLCA. As of May 2012, it includes 445 datasets

Table 2 Features of major Japanese LCI databases

Name	Availability (language)	Modeling	Reference
JLCA LCA database	Online for Member of JLCA (Japanese)	Gate to gate process datasets library	JLCA, 2012
IDEA	In LCA software 'MiLCA' for free (Japanese/English)	Interlinked process based database	Tahara et al. 2008
The basic secondary database for carbon footprint communication program	Online for free (Japanese)	Calculated process based database	JEMAI 2012
3EID	Online for free (Japanese/English)	Environmentally extended input–output database	Nansai et al. 2012
Toshiba IO database	In commercial software 'Easy LCA' and 'SimaPro' (Japanese/English)	Environmentally extended input–output database	Kobayashi et al. 2007

collected by industry associations and 431 made by research institutes. Recently added datasets are, for example, about semiconductor parts and liquid crystal display panels production processes provided by the Japan Electronics and Information Technology Industries Association. In addition, the Japan Expanded Polystyrene Association provided datasets of EPS recycling processes. Not only primary material production process data, but also mid-stream and recycling processes are getting published.

Inventory Database for Environmental Analysis (IDEA) is a database developed by National Institute of Advanced Industrial Science and Technology and Japan Environmental Management Association for Industry (Tahara et al. 2008). It is a process-based interlinked database consisting of approximately 3,000 datasets. By utilizing dozens of Japanese statistics, it has achieved to encompass activities of the primary and secondary sectors of the economy in Japan. In this database, there are coarse (e.g., plastic), fine (e.g., polyethylene), and finer (e.g., high density polyethylene) classifications' datasets, and a user can select more appropriate datasets from the database for his/her LCA case study. IDEA is available in an LCA software named MiLCA (JEMAI 2012a).

A dedicated secondary database was developed in the Japanese carbon footprint pilot project conducted from FY 2009 to FY 2011 as a CFP program, which was inherited in the carbon footprint communication program in Japan (JEMAI 2012b). More than 900 datasets were provided from IDEA and nearly 200 were provided by industry associations. The third-party experts reviewed each dataset before registration to the database. It is recommended for an applicant of the carbon footprint label to use this database.

As the LCI database calculated from environmentally extended input–output tables, 3EID (Nansai et al. 2012a) is widely adopted for hybrid LCA. In 2010, embodied energy and GHG emissions intensities based on the 2005 Japanese input–output tables have been released, in addition to the databases based on 1995 and 2000 tables. Since each dataset expresses environmental burdens in monetary unit, it is utilized for, e.g., an environmental burdens automatic calculation system of purchasing activities by linking credit-card bill information (Aeon Integrated Business Service 2012).

The Toshiba IO database (Kobayashi et al. 2007) is also the LCI database derived from environmentally extended input–output tables. In this database, each dataset is converted into physical unit from monetary unit by using the average price of approximately 3,700 products. Major imported products (e.g., aluminum ingot, iron ore, crude oil, etc.) are evaluated by the process analysis method to improve the accuracy of the database. Also, the database includes elementary flows of major resources such as crude oil, iron, copper, zinc, and nickel.

Besides these databases, there are several databases that focus on a particular industry or an emerging environmental impact category. For example, the Architectural Institute of Japan has developed an LCA tool including a database (AIJ 2006) for the construction industry. Furthermore, environmentally extended input–output databases focusing on water consumption are available on the internet (Itsubo 2012).

Thus, distinguishing databases have been developed and used in Japan. The challenging issues database managers face are data collection of a variety of elementary flows for comprehensive impact assessment, advancement of modeling method, sustainable framework of database maintenance and international collaboration.

6 Outlook

LCA in Japan is very widespread, so we could cover only a couple of scientific progresses in LCA in Japan since 2000. There have been strong needs and interests in methodological developments and applications of LCA, which will be further increasing. Therefore, we are sure that LCA in Japan will further develop and contribute to progresses in the world.

While we have been writing this editorial, a decision was made for re-starting a nuclear power plant located in the Fukui Prefecture. The government officially stated that they have confirmed the safety of the nuclear power plants. We are not sure whether we can trust this message. Anyway, we have noticed how difficult it is to include rare incidents in LCA. The share of each electricity generation technology will drastically change Japan years to come. So, how shall we deal with the LCA database, especially electricity grid mix? What about the impact of nuclear power? It should be further discussed how we can include the risks and accidents, etc. into LCA. We hope that our experiences will be of help for consensus building.

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